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A Versatile Micro-Computer Controlled High Speed Data Acquisition System Applied to Compressors

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A VERSATILE MICRO-COMPUTER CONTROLLED HIGH SPEED DATA ACQUISITION SYSTEM APPLIED TO COMPRESSORS

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ABSTRACT

A brief account is given of an early system used in 1967 and 1973 to acquire experimental data from reciprocating compressors. The later system was controlled by a mini-computer, had a multiplexed configuration, and had to operate in real time. Data could be read at a rate up to 100,000 readings per second: the maximum rate per channel was inversely proportional to the number of channels employed.

A description follows of a parallel configured system developed in 1982 which is capable of data acquisition at the rate of 33,000 readings per second for each channel with virtually no limit on the number of channels which can be employed. Each channel is fitted with an individual analog-digital converter and digital store and operates in real time: channels are triggered and read simultaneously and data is subsequently transferred relatively slowly from the digital store to the memory of the controlling micro-computer.

The transferred data can then be processed and either stored or displayed in digital or graphical form. The system has operational advantages over, and is cheaper than, the earlier multiplexed system. One of its many applications is to measure the pressure in a cell of a sliding-vane oil-flooded rotary air compressor during a cycle of operation.

INTRODUCTION

The usefulness of mathematical models which simulate compressors and the system within which they operate is now widely accepted by designers. The nature of the model used depends on the duty required of it. For example, in a model which predicts the loading on pistons and bearings it is possible to describe the automatic valves of the compressor very crudely, e.g. as off/on devices to control the flow into and out of the cylinder. However, if valve failure is a problem such a model is of little value: a model is then required which will describe in detail the behaviour of the valve during a compressor cycle. Hence a model should be designed to provide information relevant to a stated problem, at minimum time and cost of developing and running the appropriate computer programs.

The equations which form such models have to be simplified sufficiently so that a mathematical solution can be obtained. The simplifying assumptions introduced raise doubts about the ability of the model to simulate adequately the complex physical situation. If it can be established that the model is valid for its particular purpose, the model serves thereafter as a cheap and rapid aid to the designer. The only practical method of assessing the accuracy of a model is by comparing predicted results with experimental results. This assessment depends on how the inevitable differences between predictions by the model and corresponding experimental results are interpreted, thus experimental records should be as accurate as can be achieved within the limits of time and cost. The problems posed in obtaining experimental results of sufficiently high quality can be formidable. This paper outlines the development of equipment to achieve this end, from the use of a conventional U V recorder (1967) through a mini-computer controlled high speed data acquisition system using a multi-plexer (1972) to a micro-computer controlled system using a parallel configuration (1982). In circumstances where compressor development is being undertaken solely by experiment, qualitative trends in results may suffice. When assessing simulation models absolute values have to be measured accurately thereby increasing the demands on the experimenter and on the sophistication of instrumentation. Experimental readings have to be obtained at a large number of small intervals during a compressor cycle and hence the acquisition of data must be at a high rate. At a rotational speed of say, 1,500 rev/min the time required for $\frac{1}{2}^{\circ}$ rotation is only 56 μs. To avoid inaccuracies caused by variations from cycle to cycle in the compressor (variations not necessarily negligible in terms of the accuracies being sought) all measurements should be made during one compressor cycle. The transducers for each channel have to be small enough to be incorporated in the compressor: the response of the transducers must be fast, the calibration known and the signal free from drift. The overall system must have a response time compatible with that of the transducer, and provide a signal output which has been linearised, (if necessary) and scaled. The system must be capable of accommodating several channels. To meet such demanding criteria it is imperative that the system be controlled by computer.

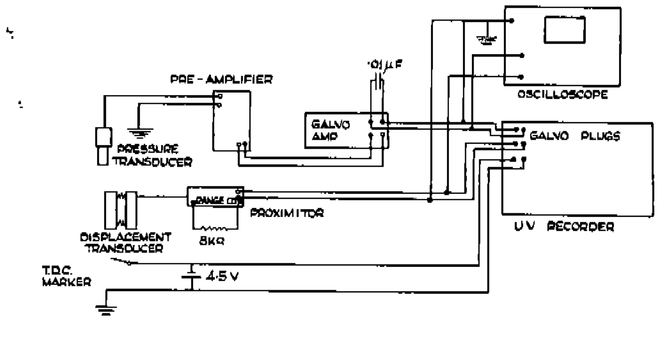

Fig 1 Instrumentation for conventional measurement of pressure variation and valve displacement employing a U V recorder (1967).

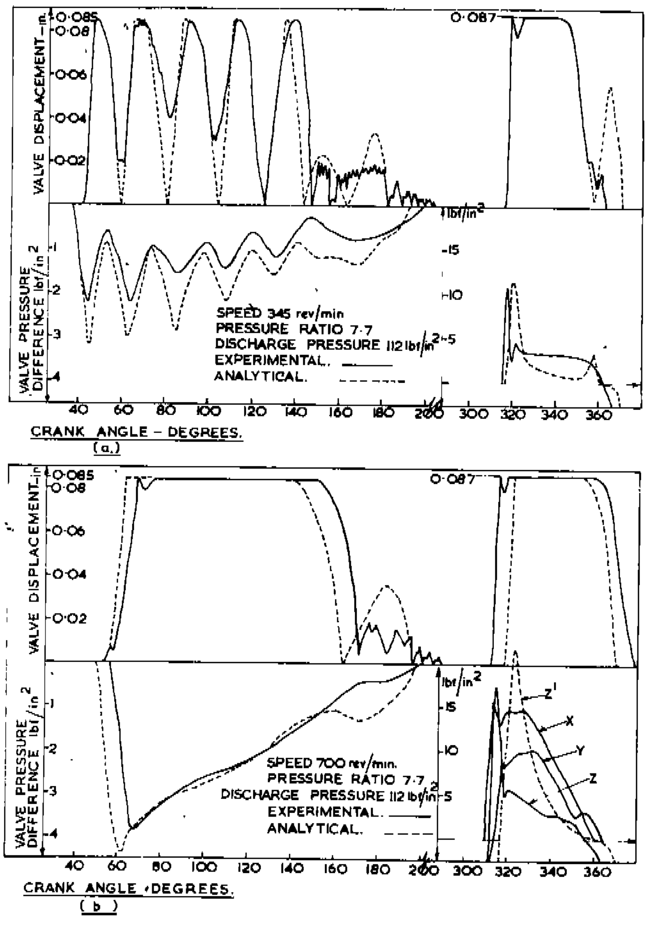

Fig 2 Sample of experimental results (and analytical predictions) of suction and discharge valve displacements and pressure differences across the valves of a reciprocating air compressor, at two speeds (a) and (b), (1967). Reference (1).

PREVIOUS SYSTEMS (1967 and 1973)

In 1967 experimental records of valve displacement and pressure drop across the valves of a reciprocating air compressor were obtained using a 12 channel ultra-violet (U V) recorder and a cathode ray oscilloscope (C R O). These items of equipment, illustrated schematically in Figure 1, imposed constraints on the number of channels which could be monitored simultaneously: the experimental traces were recorded in batches, so the records (full lines) in Figure 2 do not all pertain to the same compressor cycle. Although each batch included a reference crankangle mark, errors were present in the phasing of traces relative to each other. Accurate experimental records of the pressure difference across the discharge valve were particularly difficult to obtain. The cylinder pressure (X, bottom right of Figure 2) and the pressure in the discharge plenum chamber, Y), were measured separately to obtain the pressure difference across the valve (Z=X-Y). There was also an element of uncertainty in fixing the datum of these traces. Additional errors accrued in the laborious manual task of linearising, scaling and transposing the traces. In the end the experimental records of pressure difference were not as accurate as was desired for comparison with the predicted pressure difference (Z') across the discharge valve.

An alternative data recording and processing system was needed which would (a) avoid the several well known limitations of a U V recorder and C R O (b) record the signals from all channels during one cycle of the compressor (c) remove errors of phasing by reading each transducer channel almost simultaneously at a precisely known time (crankangle) (d) provide more detailed records during a part of the cycle of interest (e.g. during the few crankangle degrees during which a valve was opening) (e) remove the inaccuracies and tedium involved in the manual scaling, linearising and final display of records in graphical form and (f) provide accurate records in digital form for subsequent calculations and for comparison with predictions made by appropriate simulation models.

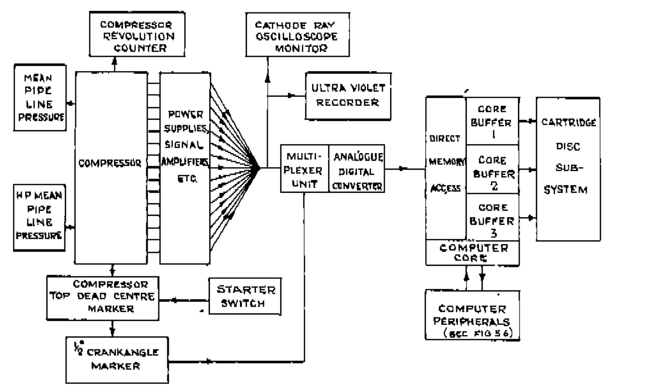

Fig 3 Instrumentation and control configuration for a "multi-plexed" high speed data acquisition system controlled by Hewlett-Packard 2100 A mini-computer (1973).

A block diagram of a system which was developed in 1973 to meet these criteria is shown in Figure 3. The system described in reference (2) was based on the Hewlett-Packard 2100A mini-computer with 16K bytes in core memory, supported by a cartridge disc sub-system. Peripherals of the system included a teletype, fast tape reader, tape-punch, digital plotter and a high resolution visual display unit (V D U). The component which determined the rate at which data could be acquired was the analog-digital converter (A D C) which was capable of a maximum conversion rate of 100,000 readings per second. It had 10 bit resolution [9 bits + sign] and a multi-plexer with a maximum of 16 channels. The successive approximation method of conversion was employed giving an actual conversion time of 8.5 µs. Direct Memory Access (D M A) was used to utilise the full capability of the A D C but this had the disadvantage of restricting the storage capacity to about 14K bytes. If the full storage capacity including that of the cartridge-disc sub-system was to be utilised, then the system could be operated without D M A, but this caused the throughput rate to be much reduced.

The system conformed to the conventional "multi-plexed" configuration widely used at that time. In essence this meant that the signal from each channel had to pass along a single line. Since each channel was selected sequentially, signals were not acquired simultaneously but for most applications this time lag between readings was negligible in relation to the time scale of compressor operation.

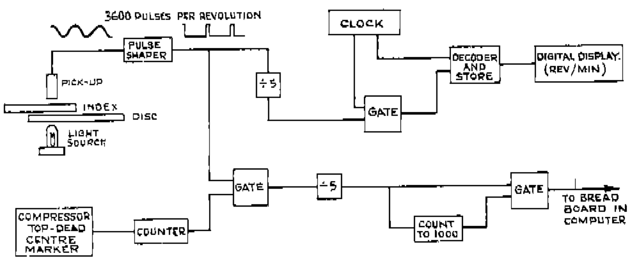

Fig 4 Arrangement of trigger pulse system. (1973)

Figure 4 shows the arrangement to initiate this system. A rotating disc and fixed index mounted on the compressor shaft provided trigger pulses at ½° intervals of crankangle, the first trigger being arranged at T D C. Thus readings were obtained from each channel sequentially but virtually simultaneously. At the maximum rate of 100,000 readings per second with N channels in use, the time interval between successive readings in one channel was 10 x N µs, and the storage available was $\frac{14K}{N}$ bytes per channel. Thus if the number of channels was increased, both the acquisition rate and the storage capacity per channel decreased. The system operated in real time so, to achieve the highest throughput rate, programming was required in ASSEMBLER language. While faster than higher level languages ASSEMBLER is more difficult to learn. The operating procedures were sophisticated so requiring an experienced user. The total hardware was bulky, relatively immobile and so became dedicated to a particular application in a fixed location.

Figure 5 illustrates experimental records (broken lines) of pressures and valve displacements during one cycle of a two-stage inter-cooled air compressor.

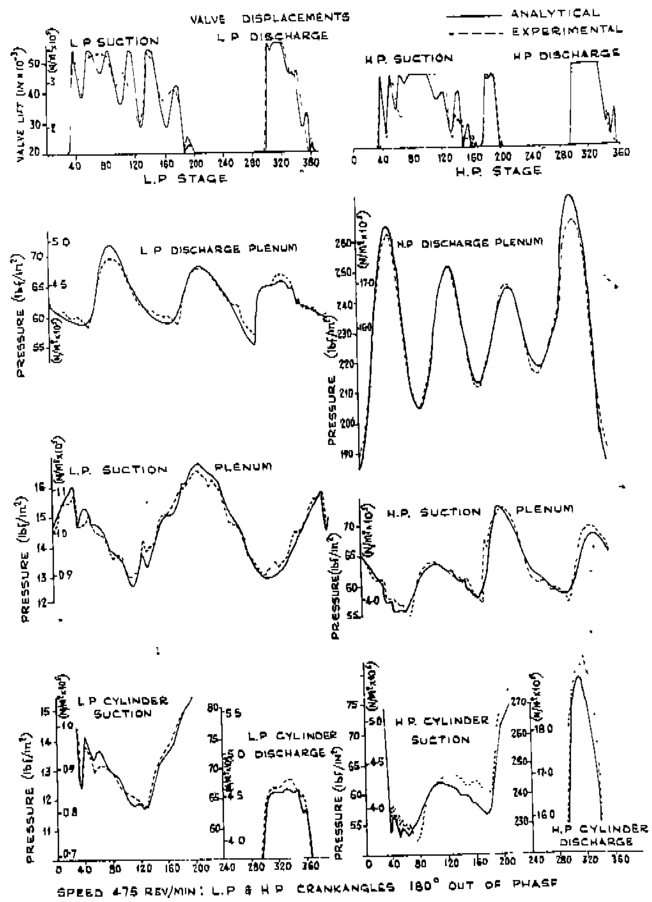

Fig 5 Example of experimental results (and analytical predictions) for a two-stage intercooled air compressor. Experimental records obtained by a "multi-plexed" system (1973). Reference (2).

NEW SYSTEM (1982)

Developments in modular electronic hardware, miniaturisation and the standardisation of bus systems, during the last decade, have led to data acquisition systems which use a parallel configuration. For comparison the earlier multi-plexed system is shown schematically in Figure 6(A) and the newer system in Figure 6(B).

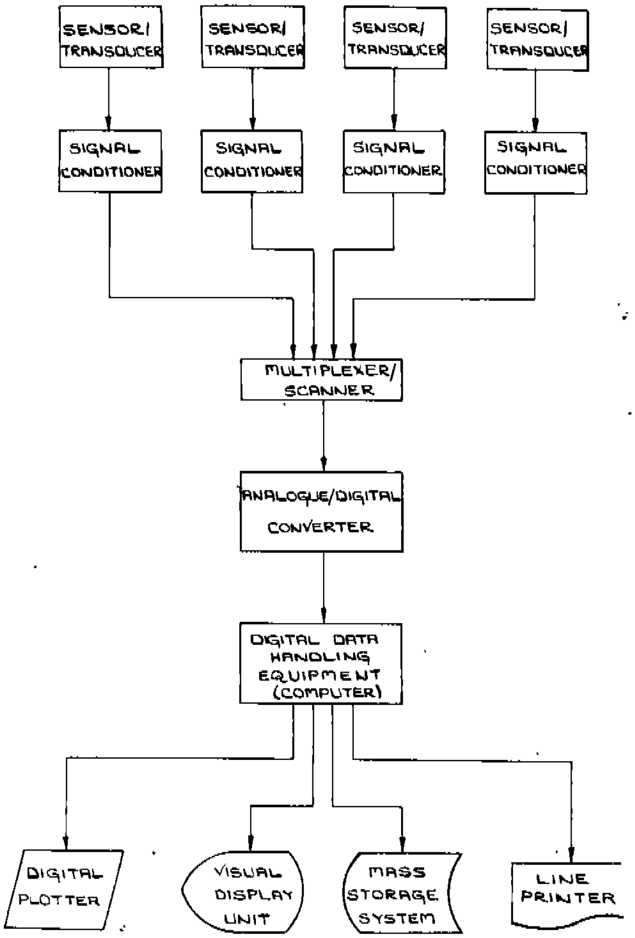

Fig 6(A) High speed data acquisition system using a "multi-plexed" configuration.

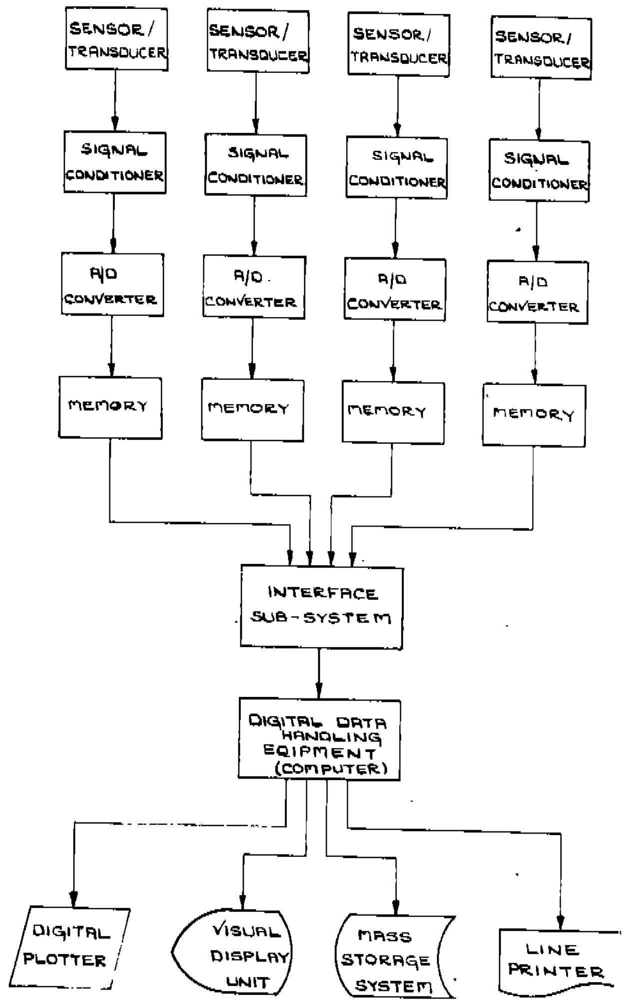

Fig 6(B) High speed data acquisition system using a "parallel" configuration.

At the speeds of modern compressors e.g. 2,500 rev/min the total time available for data acquisition at $\frac{1}{2}°$ intervals of rotation is $33\mu s$. Therefore it is necessary when employing a multi-plexed configuration to either reduce the number of channels being monitored or use a faster and more expensive A D C, or both. By using a parallel configuration the time available per channel is $33\mu s$ and any number of channels may be installed. The arrangement which was developed is shown schematically for three channels in Figure 7. It is based on a Hewlett Packard 6942A multiprogrammer which is essentially an intelligent interface unit with its own 16 bit micro-processer and a resident 12K x 16 bit read-only-memory (R O M) with a unique set of 32 mnemonic action-oriented instructions. Each channel includes an analog-digital converter (A D C) card and a memory card. Acquisition is paced by a timer/pacer card. A Hewlett Packard 9845 desk top micro-computer, with its own inbuilt V D U, store and printer, is used to control the whole system. The only external peripheral was a digital plotter for high resolution hard copy graphical output.

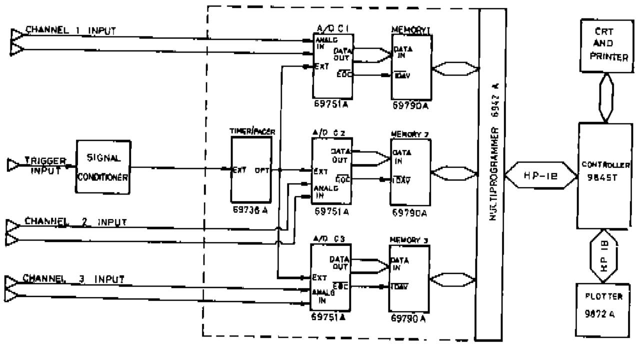

Fig 7 Three channel high speed data acquisition system, using a "parallel" configuration controlled by Hewlett-Packard 9845 desk-top micro-computer.

To relate data to the angular rotation of the compressor a trigger device mounted on the compressor rotor shaft is used to initiate the timer/pacer card. The trigger is a reflective opto switch (integral with the torquemeter employed) which is set to pulse at a known position of angular rotation, e.g. top-dead-centre in a reciprocating compressor or engine, or the centre of the sealing arc of a sliding-vane rotary compressor. Following this initial triggering the pacer card provides pulses at regular intervals to initiate the analog-digital (A D C) cards. The data converted by the A D C is stored on the individual memory cards, each of which has a capacity of 4K x 16 bit words: data from each channel obtained at ½° intervals of rotation during five compressor cycles can be stored.

The earlier multi-plexed system was programmed in ASSEMBLER in order to achieve a fast rate of execution of instructions in real time. The new system was controlled by a programme written in extended BASIC: while simple to write, execution is relatively slow. However this does not affect the speed of data acquisition which is not done in real time by the controller. The controller instructs and sets up all the cards in the multiprogrammer so acquisition commences in receipt of the initial signal from the external trigger. Based on the speed of rotation of the compressor the computer sets the pacer card for trigger pulses thereafter at ½° intervals of angular displacement. However this can be overriden by the operator who must then specify a time interval for the trigger pulses. This time interval cannot be less than 31 μs in recognition of the maximum acquisition rate of the analog-digital (A D C) card. Following a pulse, each channel acquires data independently of all other channels and hence can approach the maximum channel rate of 33,000 readings per second and store the digitised information on the individual channel memory cards. Data from all channels is thus acquired simultaneously. This last feature is not of particular advantage: the sequential reading of the channels following a pulse in the earlier multi-plexed system was virtually simultaneous for all practical purposes.

When the memory cards are full the multiprogrammer terminates acquisition of data and sends a signal to the controller which then begins the relatively slow process of transferring the data from the memory cards to the controller memory. The data can then be retrieved, processed and displayed as required.

USE OF THE SYSTEM

The new system was used to acquire experimental data from an oil-flooded sliding-vane air compressor over a range of discharge pressures and rotational speeds up to 2500 rev/min. The layout of the test plant and instrumentation is shown in Figure 8. To monitor the pressure within a cell during a complete compressor cycle small strain-gauge type pressure transducers were mounted in the face and ends of the rotor. The transducers

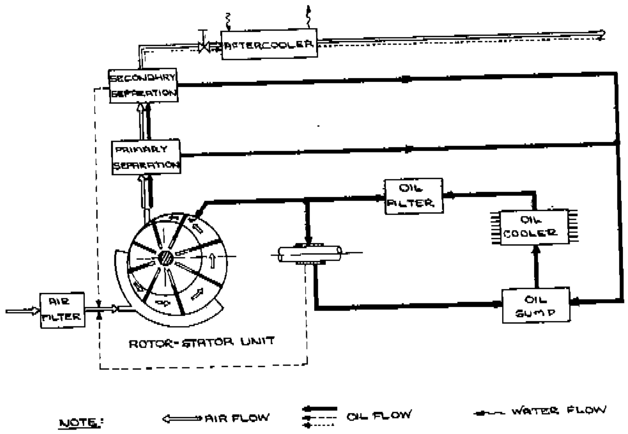

Fig 8 Test circuit for oil-flooded sliding-vane air compressor.

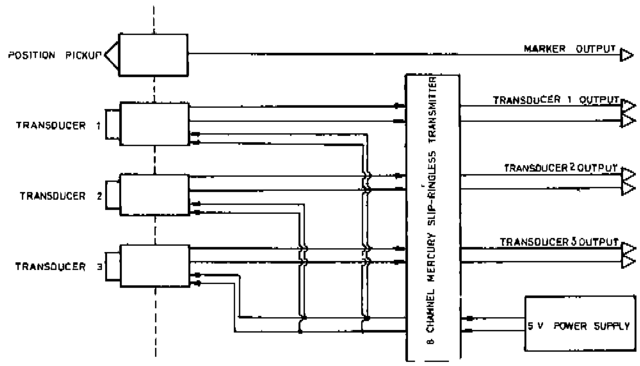

Fig 9 Signal transmission from three transducers mounted on a rotor, through an eight line mercury slip-ringless transmitter.

used were passive devices requiring a source of power. Hence two lines were needed for the power supply and also for output. The signal from the transducers in the moving rotor were brought out of the compressor to the stationary data acquisition system via a mercury slip-ringless transmitter. The maximum number of lines available through the slip-ringless transmitter was eight so the arrangement was limited to three channels as shown in Figure 9 (and Figure 7). A sample of the records obtained is shown in Figure 10, these records being required to assess the performance of the compressor and also for comparison with predictions from an appropriate computer simulation model. Figure 10 shows the pressure variation in one cell of the compressor over two + revolutions, at a speed of 1450 rev/min. The suction pressure was atmospheric and the nominal discharge pressure was 100 lbf/in^2 gauge.

CONCLUSIONS

Advances in electronic hardware have made it possible to construct a system to acquire experimental data at high speed from compressors. A new system with a parallel configuration controlled by a desk-top micro-computer was employed to record the pressure/time history in a cell of an oil-flooded sliding vane air compressor. The system could be applied to a variety of similar applications with a minimum of modification.

The system was capable of a maximum throughput rate of 33,000 readings per second per channel with virtually no limit to the number of channels which may be installed. In the initial application the number of channels was limited to three on account of the number of lines through the slip-ringless transmitter employed to transfer data taken from transducers mounted on the moving rotor.

The system can provide results in digital or graphical form to a high level of accuracy provided the characteristics of the transducers are known. The results can be linearised, scaled and generally manipulated as circumstances dictate. Being computer controlled the system operates with great ease and speed compared to relatively inaccurate systems such as U V recorders which require laborious manual processing of the data. The parallel configuration of this (1982) system had all the advantages of the earlier multiplexed (1973) system, plus a simpler operating system and easier writing of the control program in extended BASIC. It was capable of expansion to an almost unlimited number of channels and hence a higher total throughput rate. It was less bulky, more mobile, much less expensive and altogether more versatile.

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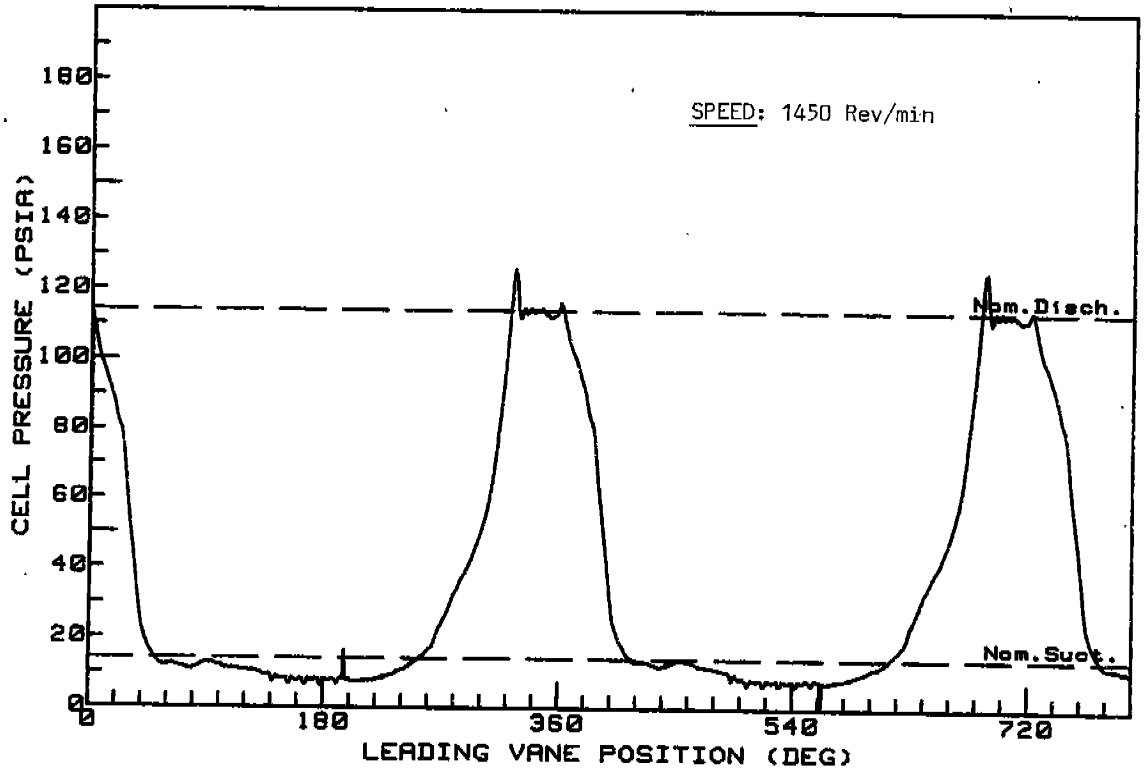

Figure 10 - Pressure-time History in One Cell of a Sliding-Vane Air Compressor, Obtained by the "Parallel Configured" High Speed Data Acquisition System (1982).